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# MEASUREMENTS OF PROPELLER INFLOW DURING TRANSIENT TURNING OF A SHIP MODEL BY FIBER OPTIC LDV

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**ABSTRACT**

A fiber optic Laser Doppler Velocimetry system was developed for the flow measurement around a ship model in the towing tank. The system was used to measure unsteady flow in front of an operating propeller in the turning condition of a ship model in order to grasp the characteristics of propeller inflow field during the transient turning motion. From the measured data, it is found that the propeller inflow field changes complicatedly with heading angle of the ship model during the transient turning motion, and the axial velocity gradient in circumferential direction becomes steeper as a whole.

The present measured data are considered to be useful to understand the characteristics of propeller inflow in the transient turning condition and to develop more precise prediction method of ship maneuvering motion and propeller vibratory forces.

## INTRODUCTION

In recent years, the worldwide environmental problem becomes major interest in political, scientific and engineering fields and various countermeasures are discussed for protection of the earth environment. The grounding accident of the very large crude oil carrier "Exxon Valdez" in 1989 resulted in the turning point of reconsidering the ship structure, operation and so forth in the shipbuilding industries and shipping worlds.

On the other hand, the Sub-Committee on Ship Design and Equipment of International Maritime Organization (IMO, 1988) recommended that the maneuvering information in the form of the pilot card, wheelhouse poster and maneuvering booklet should be provided for the sake of the safety in navigation. This means that more precise evaluation and prediction of the ship maneuverability are desired for the prevention of oil pollution by collisions, rammings and groundings of ship.

The numerical simulation of ship maneuvering motion is one of the most practical prediction and evaluation methods of the ship maneuverability. Nowadays, the numerical simulation method based on the hydrodynamic force model can predict fairly well the maneuvering performance, such as steady state turning characteristics (Fujino, Kijima & Hamamoto 1990). However, more precise prediction of the characteristics of initial phase of turning motion is considered to be useful for the prevention of the collision and grounding. These maneuvering characteristics are considered to connect closely with the stern flow field at transient phase of turning before a ship reaches a steady turning. It is also experienced sometimes that ship stern vibration becomes larger during transient turning motion rather than running in a straight or in steady turning motion.

These facts suggest that propeller inflow at the transient condition such as the initial phase of the turning changes considerably from that at the steady state condition. In order to predict more precisely ship's maneuverability and propeller vibratory forces, therefore, it is necessary to know the propeller inflow at the transient condition, which affects significantly on the thrust, torque and side forces of the propeller.

Usually, measurement of steady flow around a ship model in a towing tank is conducted by use of multi-hole pitot tube. Recently, flow measurements around ship models in oblique towing condition were made by use of multi-hole pitot tube for development of mathematical model in ship maneuvering motion and further understanding of a relationship between flow field around a ship and hydrodynamic forces acting on the ship (Kasoguchi 1984, Nonaka, Fuwa & Nimura 1986, Matsumoto, Suemitsu & Kusakawa 1986).

On the other hand, as examples of unsteady flow measurement around ship models, stern flows of ship models in waves were measured by use of Laser Doppler Velocimetry (Aalbers and van Gent 1984) and a propeller type velocimeter (Himeno Chang & Ohishi 1986). However, to the authors knowledge, there is no paper with respect to unsteady flow measurement in the vicinity of an operating propeller at turning motion, to which the pitot tube can not be applied.

In the present study, a fiber optic Laser Doppler Velocimetry system is developed and is used to measure the unsteady flow in front of an operating propeller in the forced turning motion of a ship model. And in order to clarify the characteristics of propeller inflow at the transient turning condition, instantaneous velocity distributions at the plane in front of the propeller at each heading angle of initial phase of turning are obtained from the measured data. For reference, propeller forces are calculated using the above instantaneous velocity distributions to examine qualitatively the feature at turning motion of the ship.

## FIBER OPTIC LASER DOPPLER VELOCIMETRY

A few systems of Laser Doppler Velocimetry (LDV) were applied to the flow measurements in a towing tank (Kirschneck and Laudan 1980, Fry and Kim 1984). The LDV system requires a relatively large strut to support a probe and to conduct the laser beams through the water surface to the probe. The strut may disturb the flow field appreciably, especially when the ship model is turning. A fiber optic LDV adding fiber optics to the traditional LDV system is suitable for flow measurement near a ship model in a towing tank because only a small probe can be placed directly in the flow without creating an appreciable disturbance and the probe connecting with flexible fiber optic cable is highly maneuverable. A few applications of fiber optic LDV in towing tank were reported so far (Fry, Jessup & Huang 1987, Bocquet 1987, Kakugawa et al. 1989).

The two-component fiber optic LDV system for the towing tank of the Nagasaki Research and Development Center, Mitsubishi Heavy Industries (MHI) was developed.

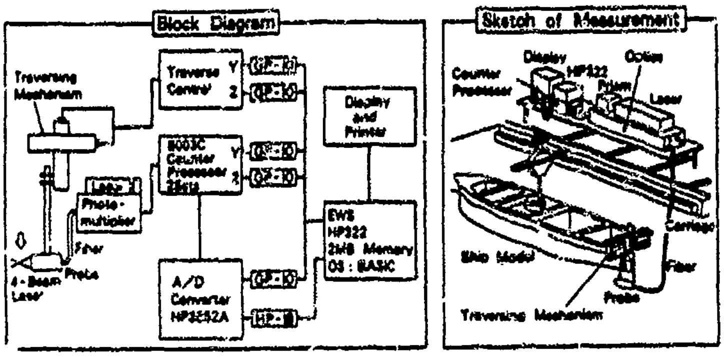


Fig.1 Schematic of Fiber Optic LDV System in Towing Tank

**Table 1 Main Characteristics of Fiber Optic LDV**

| | |
|---|---|
| Laser | Argon Ion |
| Power | 4 Watt |
| Focal Length | 200 mm |
| Beam Crossing Angle | 8.6 deg |
| Input Beam Diameter | 1.2 mm |
| Measuring Volume | 0.1 mm in Diameter<br>0.7 mm in Length |
| Frequency Range | 1 kHz ~ 25 MHz |
| Shift Frequency | 0 ~ 10 MHz |
| Fiber Cable | 9 mm in Diameter<br>10 m in Length<br>60 % Efficiency |

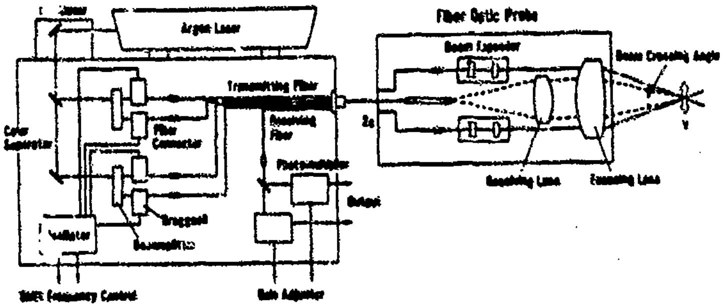


Fig.2 Block Diagram of Fiber Optic LDV

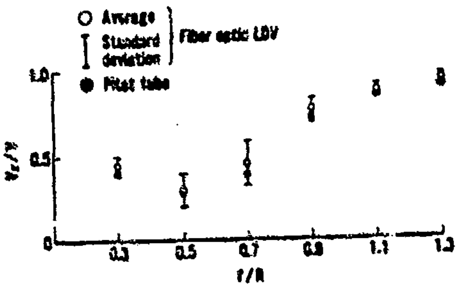


Fig.4 Comparison of Steady State Velocities Measured by Fiber Optic LDV and 5-Hole Pitot Tube

The schematic description is shown in Fig.1. The system consists of a laser tube, an optics, a probe, a counter processor, a traversing mechanism and a minicomputer (EWS). Most of them are placed on the towing carriage of the tank and only the traversing mechanism connecting with probe by supporting strut is mounted on the ship model. The cylindrical probe with cone at the head is 45mm in diameter and 200mm long, and is placed in the flow in parallel with the center plane of the ship modle. The laser beams and back-scattered lights are turned to the direction of right angle by a prism placed at the head cone of the probe. The probe is connected to the optics on the carriage with a flexible fiber optic cable, of which diameter is 9mm and length is 10m.

The minicomputer (Hewlett-Packard Model 322) is used to control the traversing mechanism in horizontal and vertical directions with an accuracy of 0.1mm, to monitor the measured velocity data and to store them on disc. The main characteristics of the fiber optic LDV are described in Table 1 and the block diagram is shown in Fig.2. A beam produced by a 4 watt Argon Ion laser is separated into two pairs of incident beams, green (wave length of 514.5nm) and blue (wave length of 488nm) by a colour separator and beam splitters, which are included in an optical unit together with four Braggcells and photomultiplier. Four laser beams are transmitted to a probe by polarization-preserving transmitting fibers. The beams pass through two focusing lens in the probe and intersect each other with crossing angle of 8.6 degrees and the focal distance is 200mm. The measuring volume is about 0.1mm in diameter and 1.7mm in length. The counter type signal processor is adopted to analyse the Doppler burst signal obtained from the light scattered by particles in the flow.

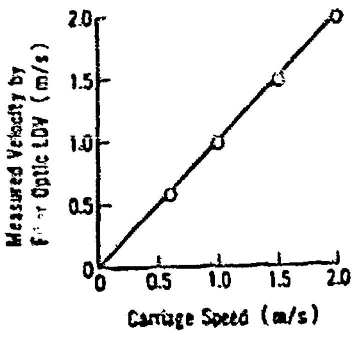


Fig.3 Comparison of Velocities Measured in Uniform Flow

In order to verify the applicability of this fiber optic LDV in the towing tank, flow measurements were performed in a uniform flow firstly by mounting the fiber optic LDV on the towing carriage. As shown in Fig.3, the measured velocities coincide well with the carriage speed and the measurement error is within 1%. Next, the steady state velocity measurements were carried out at the propeller plane of a ship model by the fiber optic LDV and are compared with those by 5-hole pitot tube as shown in Fig.4. A fairly good agreement is observed except a position of r/R = 0.7 where large velocity fluctuction is measured.

## PROPELLER INFLOW MEASUREMENTS

Before the propeller inflow measurements in the transient turning condition, verification of unsteady flow

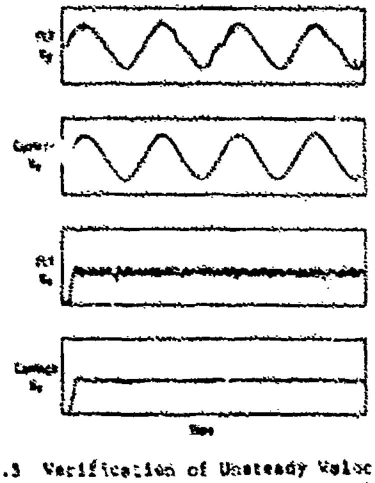

Fig.3 Verification of Unsteady Velocity Measurements by Fiber Optic LDV

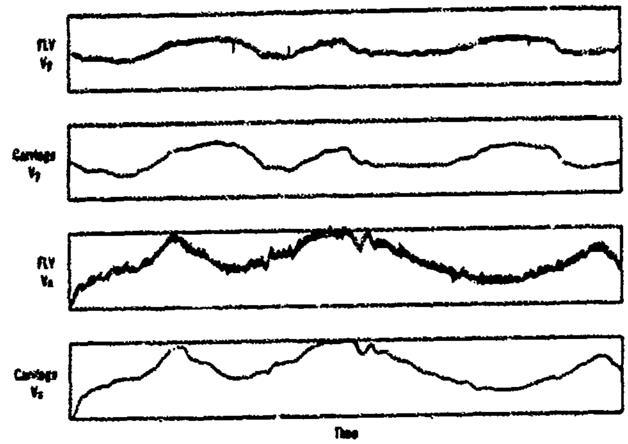


Fig.6 Verification of Unsteady Velocity Measurements by Fiber Optic LDV

measurement by the fiber optic LDV was made. The probe was fixed to X-Y carriage of the Seakeeping and Maneuvering Basin of MHI, of which dimensions are 190m long, 30m wide and 3.5m deep. In this measurement, the probe of fiber optic LDV is in open condition. Accordingly, the measured velocity must exactly coincide with the velocity of the X-Y carriage, which can be driven an arbitrary horizontal motion over the basin. The results are shown in Fig.5 when the carriage was driven to make a sinusoidal motion with constant advance speed. Fig.6 is an another example. In this case, the carriage was driven quite arbitrary. Two velocity components Vx and Vy measured by the fiber optic LDV (FLV) agree well with those of the carriage. It can be said, therefore, that the present fiber optic LDV is applicable to measure the velocity of unsteady flow in the basin.

A very large crude oil carrier model of about 7m long was used for the fiber optic LDV measurements of the flow in front of an operating propeller of about 0.25m in diameter in the initial phase of turning condition. The probe traversing mechanism was mounted on the top of the ship model and the probe was arranged parallel to the propeller shaft axis to measure the axial and circumferential velocity components. Measurements were made only upper half region above propeller shaft. When measuring at top fan-shaped region, the probe was set above the top of the ship model and laser beams passed through an acrylic part of the ship hull above the propeller.

A free turning test of the ship model was carried out beforehand at approaching speed of 1.1m/s under the condition of constant propeller revolution n = 9rps. Time history of heading angle, drifting angle, ship speed and so forth were recorded during the test. Then, a forced turning test, in which the ship model was towed and her motion was controlled by the carriage, was conducted so as to be same motion as the free turning test. The fiber optic LDV measured continuously the velocity at a fixed point in front of the operating propeller during each forced turning run.

There are not sufficient particles naturally in the Seakeeping and Maneuvering Basin of MHI for the LDV measurements. Therefore, proper particles should be seeded, which are large enough to scatter sufficient light and small enough to follow the flow. Although metallic coated sphere of 3μm in diameter is considered to be best from our experience in 3-component LDV used in a cavitation tunnel (Hoshino, Oshima & Sasajima 1987), it is considerably expensive for use in the Basin where very large quantity of particles are needed because the water does not circulate and its volume is enormous.

Nylon powder with diameters between 3μm and 5μm, which is cheaper than metallic coated sphere, was chosen for the seeding despite of its lower reflection index. The specific gravity is about 1.02. After an extensive test and trial, the best seeding way was found to inject the mixture of powder and water through a vinyl tube put

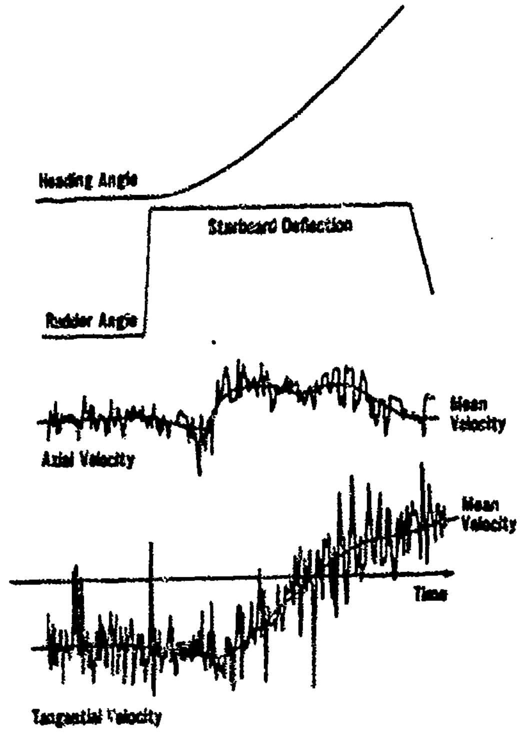


Fig.7 An Example of Data Record Measured by Fiber Optic LDV

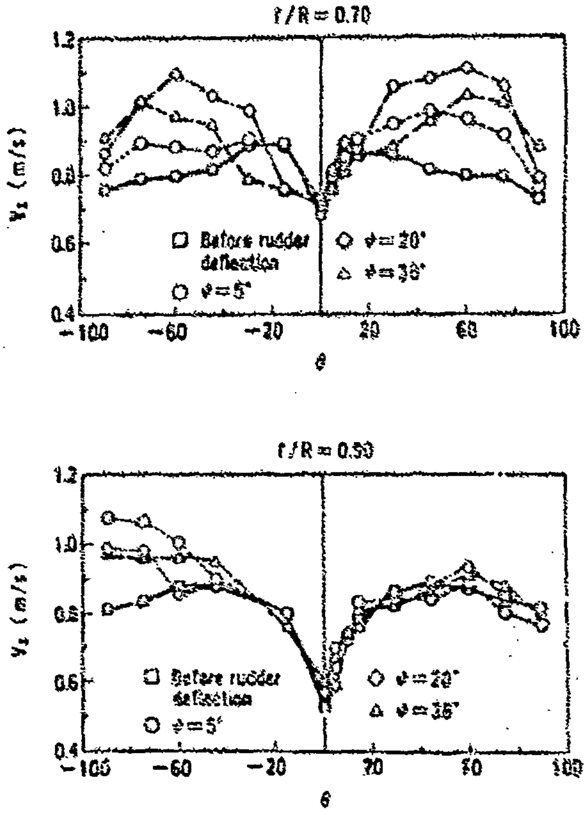


Fig.8 Axial Velocity Distributions at Typical Heading Angles in Transient Turning

at the bow of the ship model during each run. In this way, data rates have been obtained from 50 to 200 per second in the above turning tests.

## RESULTS AND DISCUSSION

The typical records of velocity measurements are shown in Fig.7. It is found that heading angle of the ship model starts to change with an appreciable time lag from the rudder deflection. The measured velocities consist of a slowly varing component as mean velocity of unsteady flow and a fluctuating component with high frequency due to turbulence. The mean axial and circumferential velocity components vary gradually with the heading angle.

The mean value of axial velocity component was read manually at typical heading angles from the measured records. Fig.8 shows the circumferential distributions of mean axial velocity component Vx at 70% and 90% propeller radii for several typical heading angles before and after starboard rudder deflection. $\theta$ denotes the circumferential angle in degree and positive sign expresses starboard side. Remarkable change of the circumferential distribution is found at $r/R = 0.7$ in both starboard and port sides. The axial velocity component increases gradually with increase of heading angle as a whole until $\psi = 20°$, and then decreases. However, no significant change is observed at the ship center line ($\theta = 0$). On the other hand, the axial velocity in starboard side at $r/R = 0.9$ changes a little with change of heading angle, while that in port side changes considerably. As can be seen in the above figures, the velocity distribution of propeller inflow changes complicatedly during the turning motion.

In order to know more visually the change of propeller inflow during the transient turning motion, instantaneous mean velocity contour curves at four typical heading angles are shown in Fig.9. One can observe that the velocity gradient in circumferential direction becomes more severe at the transient phase of turning rather than that before rudder deflection, and that at $\psi = 20°$ is most severe among them. Further, it can be seen that higher velocity region appears inside the propeller disc in starboard side and outside the propeller disc in port side during the transient turning motion. As mentioned above, the propeller inflow field is changing from moment to moment during the turning action and becomes to be unsymmetry with respect to the ship center plane.

The propeller inflow is known to play an important role in ship maneuvering motion. Because the propeller thrust is highly dependent on the propeller inflow velocity and is closely related to the strength of propeller slip stream which affects on the rudder force very much. Further, non-uniformity of the inflow field causes lateral forces of the propeller which influences considerably on the maneuvering motion.

Therefore, in order to make more precise numerical simulation of a ship maneuvering motion, it may be of great help to take the knowledge on the propeller inflow obtained in this experiment into account. For example, the present results may provide valuable data to examine and to improve the hydrodynamic models of the propeller inflow velocity which have been proposed so far (Fujino, Kijima & Nakamoto 1983). For reference, the propeller lateral forces are approximately calculated by use of the measured propeller inflow field and the ratio of that in transient turning motion to that in straight running motion is shown in Fig.10. It is found to exist about 10% variation of the propeller lateral force during turning motion. The calculated thrust fluctuations of one blade of the propeller are also shown in Fig.11. An amplitude of these fluctuation at the transient turning motion becomes greater than that before rudder deflection, and the amplitude is greatest at $\psi = 20°$. This tendency corresponds well to that of propeller inflow field seen in Fig.9, and agrees qualitatively with the feature of ship stern vibration sometimes experienced at the begining of turning motion.

## CONCLUDING REMARKS

The two-component fiber optic LDV system in the towing tank was developed for the experimental studies on the hydrodynamic problem of propeller-hull interaction.

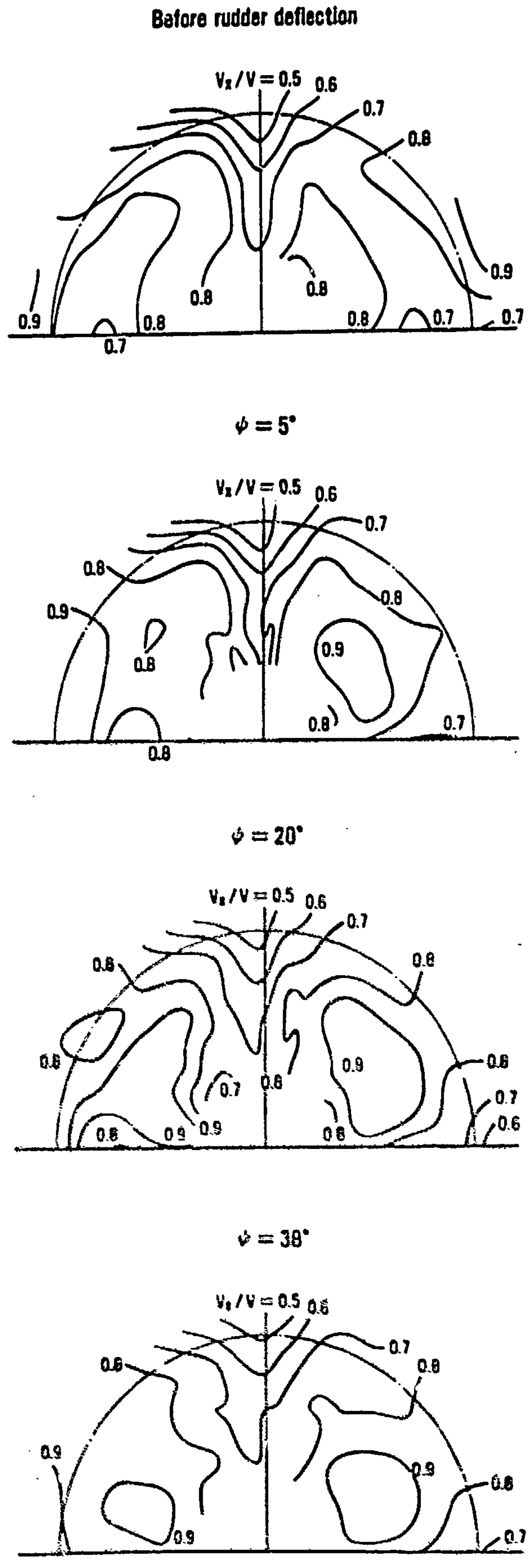


Fig.9 Instantaneous Velocity Contour Curves at Typical Heading Angles

By use of this fiber optic LDV, the propeller inflow during the transient turning motion was continuously measured in order to develop more precise prediction method of the ship maneuvering characteristics and propeller vibratory forces at the initial phase of turning motion. The measured results show that the propeller inflow velocity increases gradually with increase of heading angle except at the ship center line, and as a result, velocity gradient in circumferential direction becomes steeper during the transient turning motion. Such knowledge obtained here may not have been considered in the prediction of a ship maneuvering motion so far. However, the present measured data are just one example. In order to develop more precise prediction method on ship maneuvering motion and propeller vibratory forces, it is necessary to accumulate such data for other ship models.

## ACKNOWLEDGEMENTS

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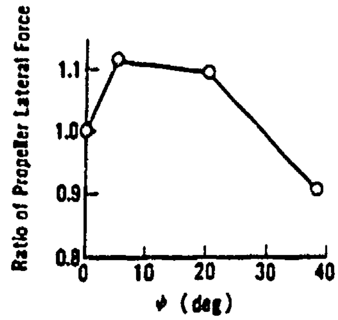


Fig.10 Variation of Propeller Lateral Force

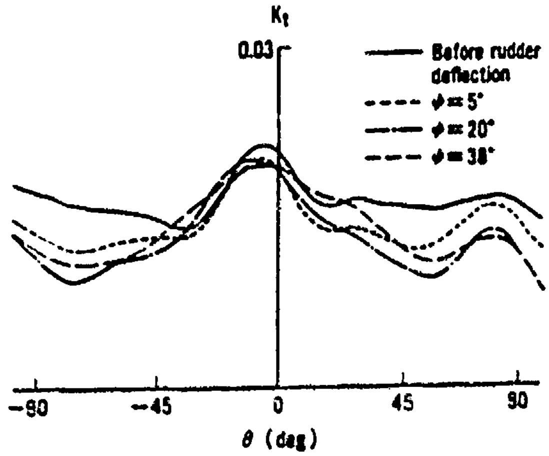


Fig.11 Comparison of Thrust Fluctuation of a Blade